SHEAR PLANE FOUND IN THE INTERIOR OF SOIL/ROCK NEAR KIZAWA TUNNEL

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ABSTRACT: Landslides triggered by earthquakes are one of the most damaging natural disasters. Recently, cutting-edge technologies such as Light Detection and Ranging (LiDAR), Interferometric Synthetic Aperture Radar (InSAR) method have allowed us to combine a spatial data set of landslides with topographical information etc. However, remote detection of landslides may cause missing slightest signs of hidden landslides. Damages to Kizawa Tunnel and other facilities in its vicinity in the 2004 Mid-Niigata Prefecture Earthquake are firstly introduced. Moreover, two wells at Sagyosho and Enryuji respectively near Kizawa tunnel were found dislocated in further survey. Dislocated wells together with other previous findings indicate that Kizawa helmet are all lying on about the same plane suggesting the presence of large shear plane and therefore the importance of thorough investigations.

Key Words: Landslides Tunnel Boreholes Wells Mid-Niigata prefecture Earthquake

INTRODUCTION

Landslides triggered by earthquake are one of the most damaging natural disasters. Damages caused by earthquake-triggered landslides can be often worse than those directly caused by intense shakes. Kobayashi (1981) found that more than half of all deaths in large earthquakes (M > 6.9) in Japan between 1964 and 1980 were caused by landslides.

In 2004, a M6.8 earthquake hit Mid-Niigata Prefecture. The hypocenter of the main shock was located at 37.3°N, 138.8°E, 13 km deep. Thousands of landslides took place, and the economic loss due to these landslides was initially estimated at 8 billion US dollars, making this one of the costliest landslide events in history (Kieffer et al. 2006). Several mountain hamlets have been rendered uninhabitable for the foreseeable future.

Both 1/6000 scale aerial photos and laser-scanned imageries of the terrain on October 23rd, 2004, namely the next day of the earthquake, were carefully read by (Oyagi et al. 2008) to make a landslide-distribution map that are open to public through the website of National Institution of Earth Science and Disaster Prevention (NIED hereafter). In addition to the thorough reading, field surveys were conducted for clear-cut evidences to support their judgments. The most updated version of the map is shown in Fig. 1.

In this figure, a remarkable number of landslides make up an about 1 km wide brush west of Kajigane syncline, which is seemingly a hidden fault projection on the ground surface as indicated by Konagai et al. (2009). Near the southern end of this brush of landslides, there is a "gap" in the vicinity of Kizawa hamlet where landslides are unusually sparse when compared with the other segments.

Konagai et al (2009) surveyed this gap area of landslides, and reported that the concrete lining of Kizawa tunnel in this area suffered a serious cracking as described herein below (Fig. 2). Since underground facilities such as tunnels follow closely the motion of their surrounding soils, the damage to

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Kizawa tunnel suggests that some dislocation took place within the interior of the ground.

Later on, the authors surveyed the area for more evidences of dislocations remaining in soils and rocks in Oct. 2008. This report describes briefly what the authors found in this area, and discusses geological aspects during the earthquake which link to the Kizawa tunnel.

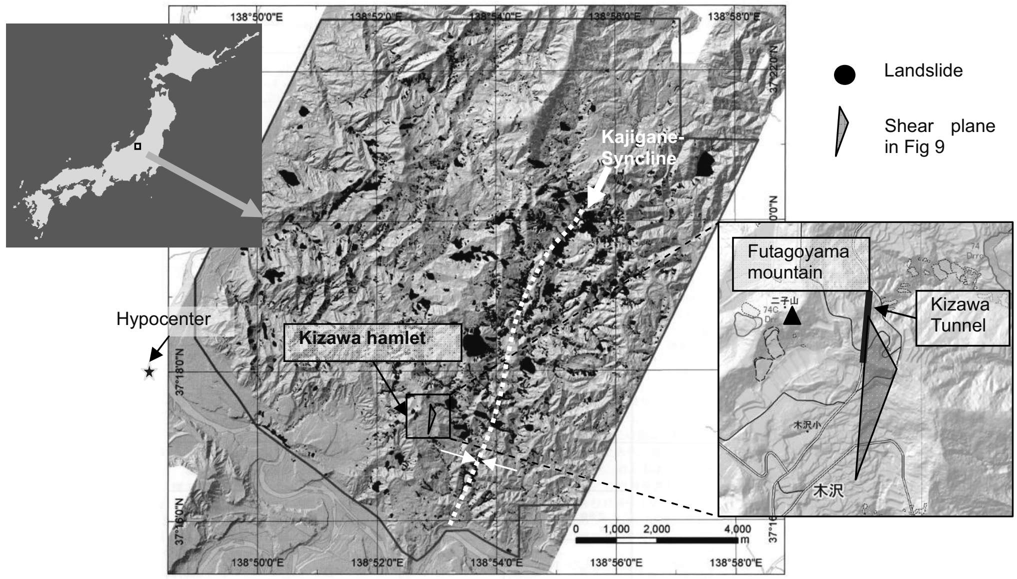

Figure 1. Distribution map of landslides caused by the 2004 Mid-Niigata Prefecture Earthquake with Kizawa area closed up. Triangle in the close-up shows the estimated shear plane as is discussed later.

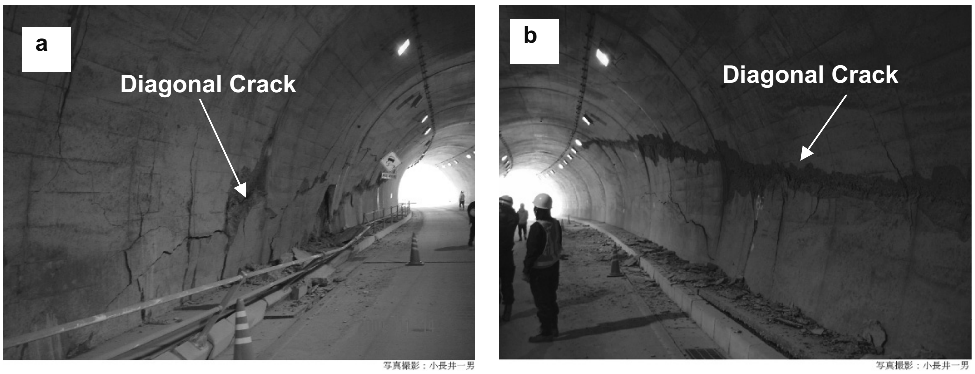

Figure 2. Diagonal cracks on both walls of Kizawa Tunnel (a) The west side of the tunnel (b) the east side of the tunnel (Photo by Konagai, K.)

DAMAGE TO KIZAWA TUNNEL*

Kizawa tunnel skims the NW-SE trending branch of Futagoyama mountain ridge (Fig. 1). Konagai et al. (2009) performed a laser-scanning to investigate the damage to inner side of the tunnel at a northern 120 m segment of the total 300 m long tunnel. This laser-scanned image (Fig. 3) (Konagai et al., 2009) shows that cracks E1, E2, and W1, W2, run diagonally up through the east and west side walls of the tunnel. The cracks E1 and E2 on the east side wall extend over 45–83 m distance from the north

* Details are all available in the reference (Konagai et al., 2009).

tunnel mouth, while W1 and W2 appeared over 38–88 m distance on the west wall.

Fig. 3 (c) shows a cross-section of the tunnel at 59 m from the north tunnel mouth. This figure shows that both E2 and W1 were folded inside the tunnel, while E1 and W2 were folded backwards. These axially opposite pairs of zigzag folds just allowed the tunnel crown at this location to shift about 0.5 m sideways with respect to the invert, and there was no sign showing that the tunnel lining was sheared in a longitudinal direction along these cracks.

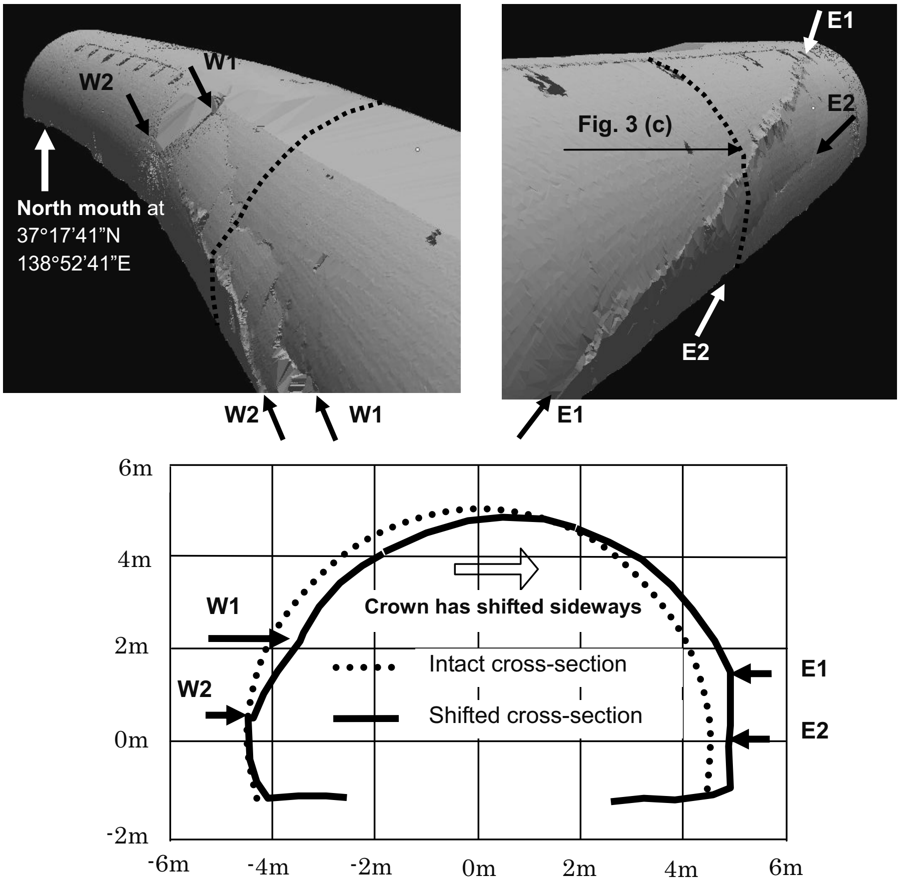

Figure 3. North segment of Kizawa tunnel. (a) West tunnel wall, (b) East tunnel wall, (c) Tunnel cross-section at 59m distance from the north mouth (looking northward) (after Konagai et al, 2009)

To identify the cause of these cracks, borehole data near the cracked part of the tunnel were first gathered. In addition, two bore holes were drilled for in-situ geotechnical tests (Konagai et al., 2009). The plan view around the Kizawa tunnel and the location of the boreholes are shown in Fig. 4.

These borehole data indicated that a shear plane with a dip of about 20–30^{o} in the northwest interior of the mountain continued to its southeastern extension, dipping about 6 to 10^{o} south. This southeastern extension is roughly parallel with the intact bed stratum of sedimentary rock. The rock mass above this shear plane was generally disturbed.

Kizawa tunnel was thus considered to be obliquely intersected by this shear plane with its 40–80 m long northern end segment and the remaining 220–260 m long southern part being embedded, respectively, in the lower intact and upper disturbed rock masses. We can judge the possible inter-layer slippage happened near the tunnels' dislocation point from the borehole near the tunnels.

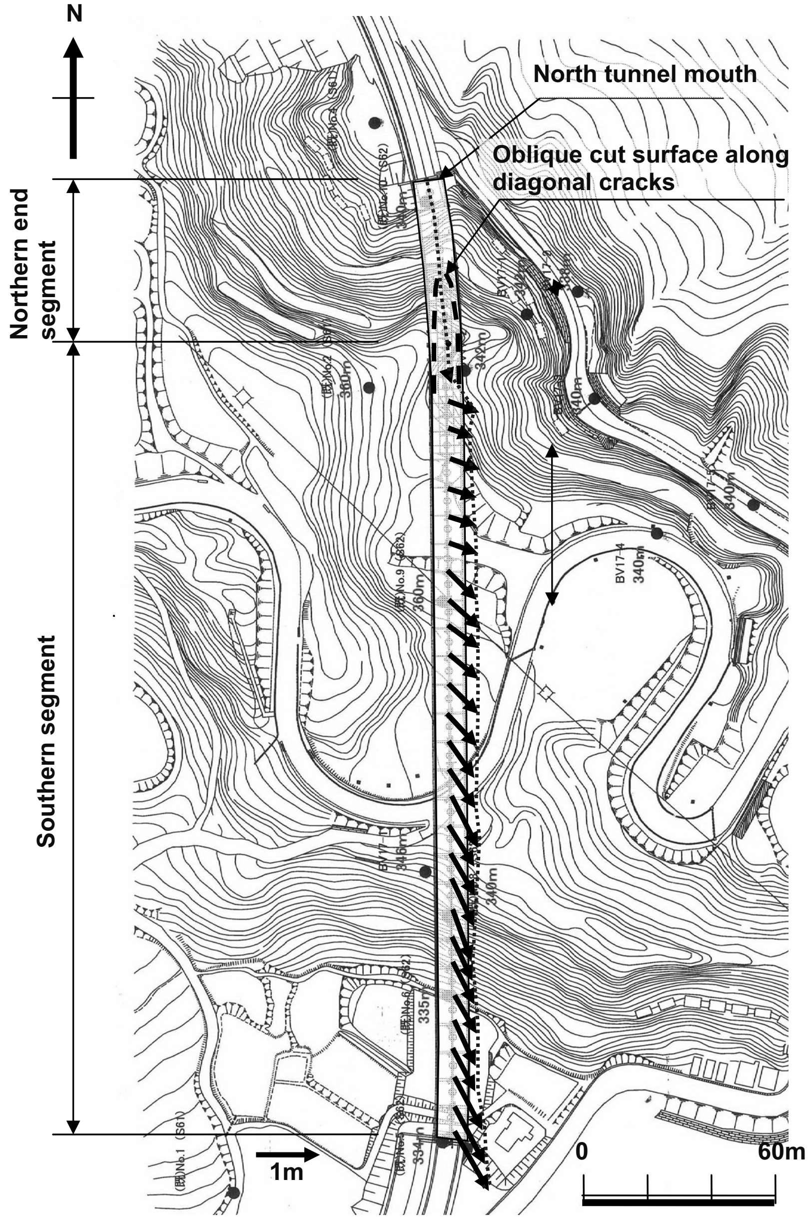

Figure 4 Earthquake-induced changes in the alignment of the road center line (Konagai et al., 2009)

The earthquake-induced change in the alignment of the road center-line was measured at every 8.8 m interval (Fig. 4, Nagaoka Regional Development Bureau et al. 2007). The north mouth of the tunnel was taken as a reference, assuming that the north segment of the tunnel was embedded in the intact and stable rock mass. It should be noted that the greater part of southern segment has shifted as a whole by about 0.5 m to the east and that south mouth has shifted nearly 1 m to the south and 0.5 m to the east. In other words, the tunnel was stretched by 1 m along the NW directions.

CRACKED FIRM ROAD ABOVE KIZAWA TUNNEL

Referring back to past earthquakes, underground facilities and/or foundations closely follow the motions of their surrounding soils/rocks. Mapping cracks on roads' pavements often allow us to capture an entire picture of the soil/rock movement. Nagaoka Regional Development Bureau et al. (2007) has compiled detailed features of cracks that appeared on the pavements of a farm road winding immediately above the tunnel. Many of these cracks did show either left-lateral or right-lateral dislocations as shown in Fig. 5.

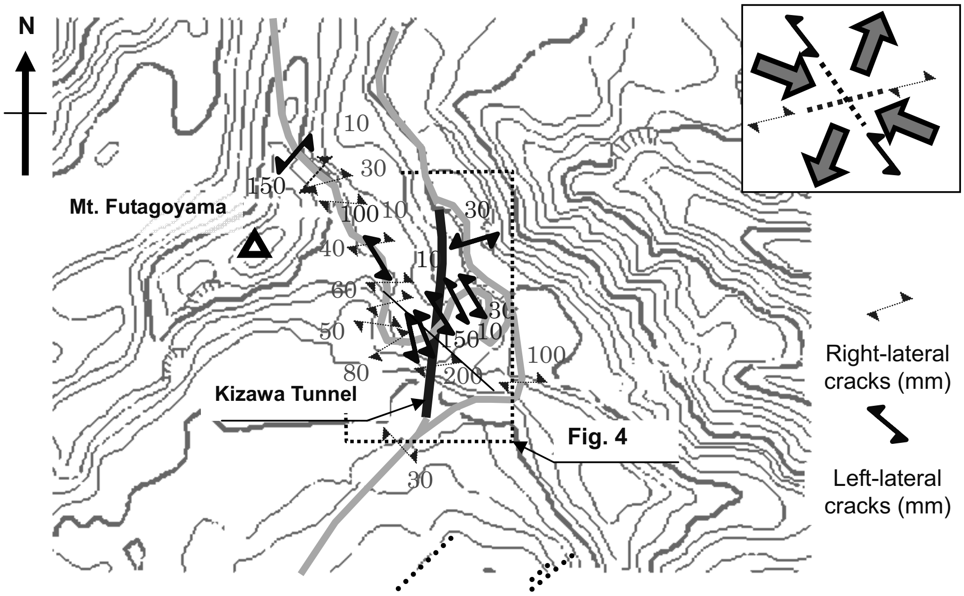

Figure 5. Right-lateral and left-lateral cracks on pavements. Figures for arrows denote dislocations in mm. (Konagai et al., 2009. Original data from Nagaoka Regional Development Bureau et al., 2007)

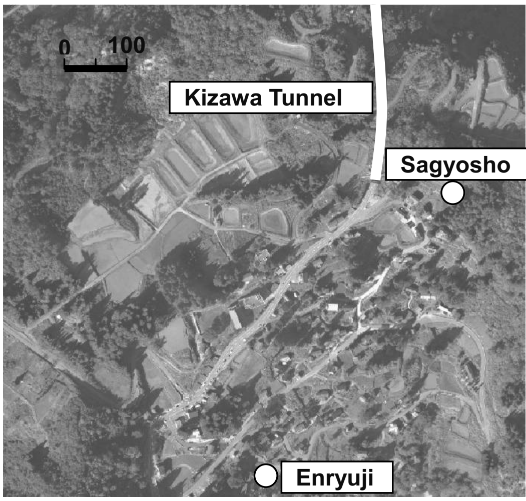

Figure 6. The two dislocated wells at Sagyosho and Enryuji respectively

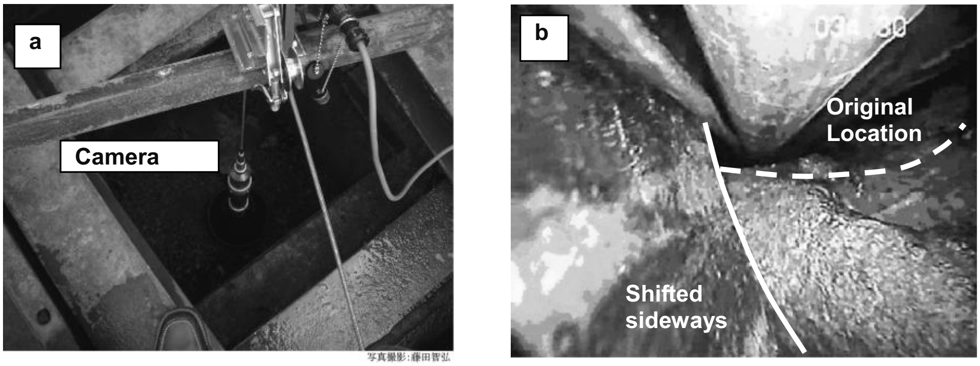

Figure 7. Determination of dislocation depth at Sagyosho well (a) lifting camera into the well (b) image showing the dislocation (looking downward into the well)

DISLOCATED WELLS

Coming out south of the Kizawa tunnel, there is a wide spread terrain sloping southeast. This terrain of Kizawa hamlet is considered to be an exposed slip surface of an old landslide. Two wells at Sagosho and Enryuji in this terrain, which were drilled for irrigation and water supplies for carp ponds (Fig. 6) were found dislocated at 32 and 20 meters depths respectively.

At Sagyosho, a borehole camera was slowly lifted down into the well using a windlass (Fig. 7 (a)). With the camera, clear dislocation was found at 32 m below the ground surface (Fig. 7 (b)). This dislocation clearly showed that the upper shaft of the well was shifted about 15 cm sideways in southeast direction. At Enryuji however, the well's inner diameter of 75 mm was too small for the camera, and therefore, its dislocation was roughly estimated as described below.

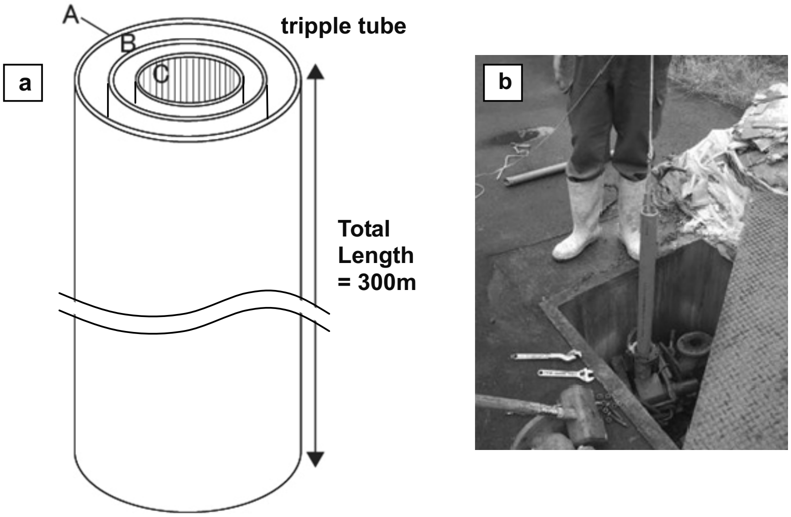

Figure 8. Determination of dislocation depth at Enryuji well (a) the configuration of the well at Enryuji (b) corresponding measuring procedure

This well at Enryoji is a triple-tube as shown in Fig. 8 whose dimensions are given in Table 1. Three PVC pipes of about 1 m long with different diameters (60 cm, 50 cm and 30 cm) were lifted down and up into the well one by one (Fig. 8(b)), and it turned out that only the thinnest pipe (30 cm in diameter) went below the dislocated point while the others stopped at this point. This indicates that the opening at this bend is smaller than 50 cm and larger than 30 cm. For the innermost pipe to be dislocated, the outermost and middle pipes are to be crushed one by one against the innermost pipe as illustrated in Fig. 8. Therefore the dislocation at this point was estimated to be larger than 140 mm and smaller than 160 mm. However, the direction of this dislocation is not known yet.

Table 1 Dimensions of triple-tube well at Enryuji

Shell	D_{out} (mm)	D_{in} (mm)	Thickness (mm)
A	216.3	205.3	5.5
B	165.2	155.2	5.0
C	85	75	5.0

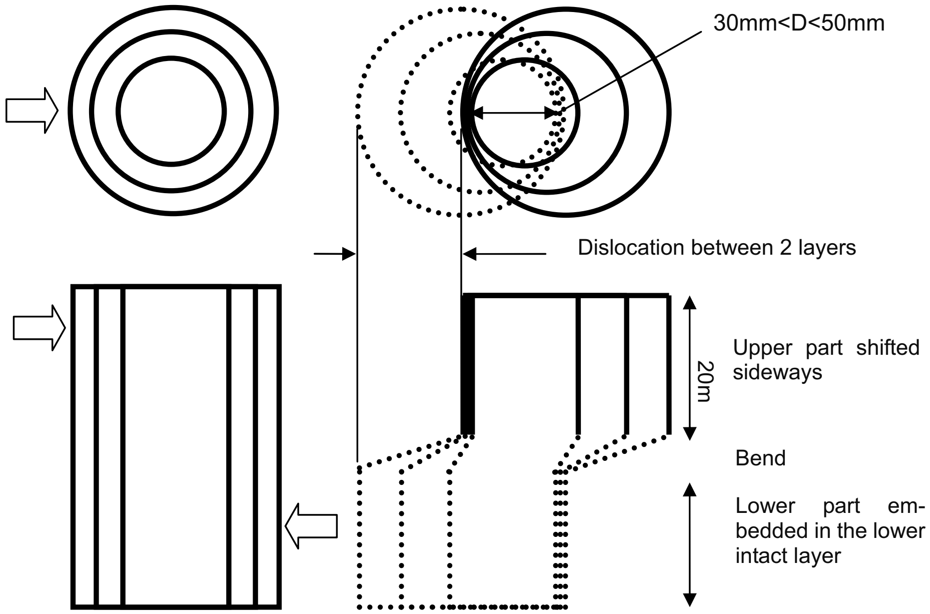

Figure 8. Scheme showing how the Enryuji well was deformed

SUMMARY: POSSIBLE STRETCH OF HIDDEN SLIP SURFACE

It is to be noted that bends observed in the well shafts, clear shear planes observed in borehole cores and diagonal cracks that appeared on both west and east concrete lining walls of Kizawa Tunnel make up a large flat plane in the interior of the sedimentary rock beneath Kizawa hamlet. The plane has a strike in almost east-west direction and dips 6.2° southward as shown in Fig. 9. This plane is thus almost parallel with the wide spread terrain of Kizawa hamlet. Considering stratified and gently folded structure of mud and silt rocks (Yanagisawa et al., 1986), this fact is suggestive of the presence of a hidden shear plane beneath the exposed slip surface of an old landslide. This plane, when it is plotted in Fig. 1, is located exactly in the middle of the gap that appeared in the wide brush of landslides densely distributed along Kajigane syncline. The soil/rock mass on this hidden plane may have shifted east to southeast sideways. For now it is not known yet if the soil/rock mass is completely stable. Moreover there may be more slip surfaces hidden in the interior of the middle raised mountain terrains of geological folding. Further detailed studies will be necessary for coping with long lasting problems for rational rehabilitations.

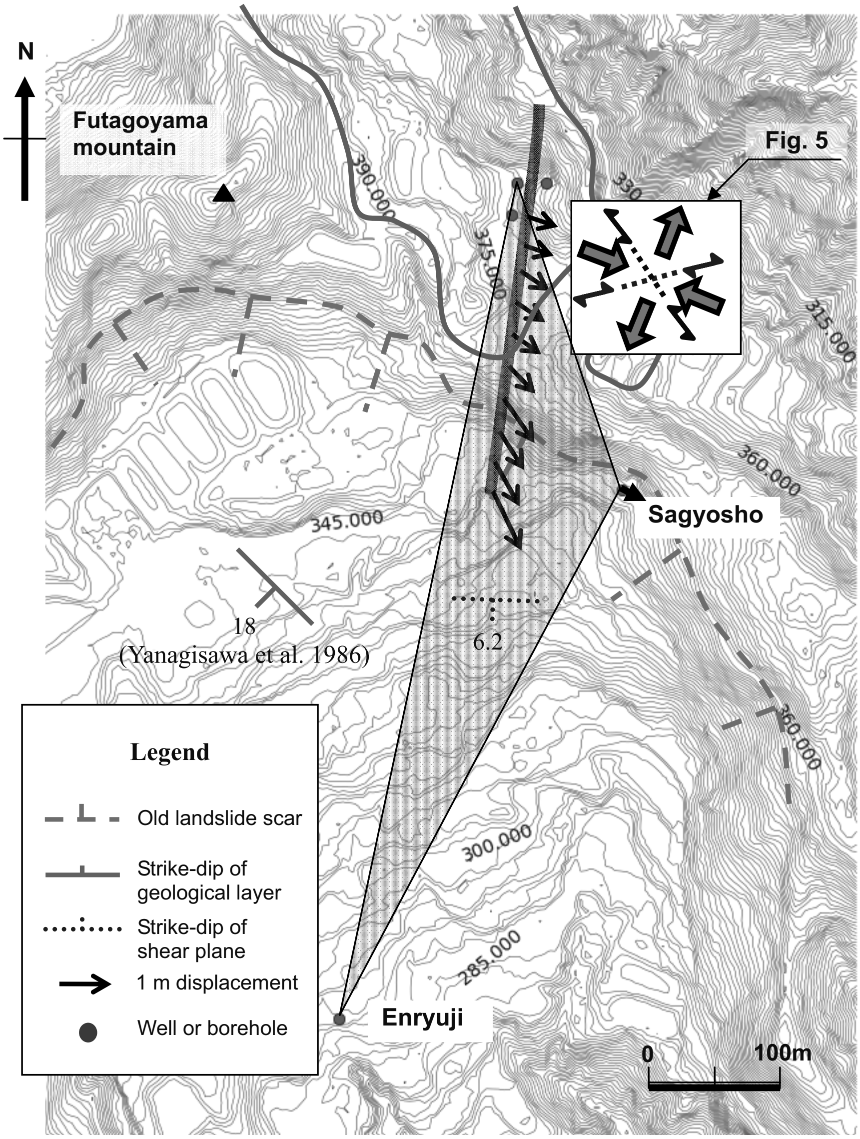

Figure 9. Shear plane related information compiled on Kizawa helmet

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